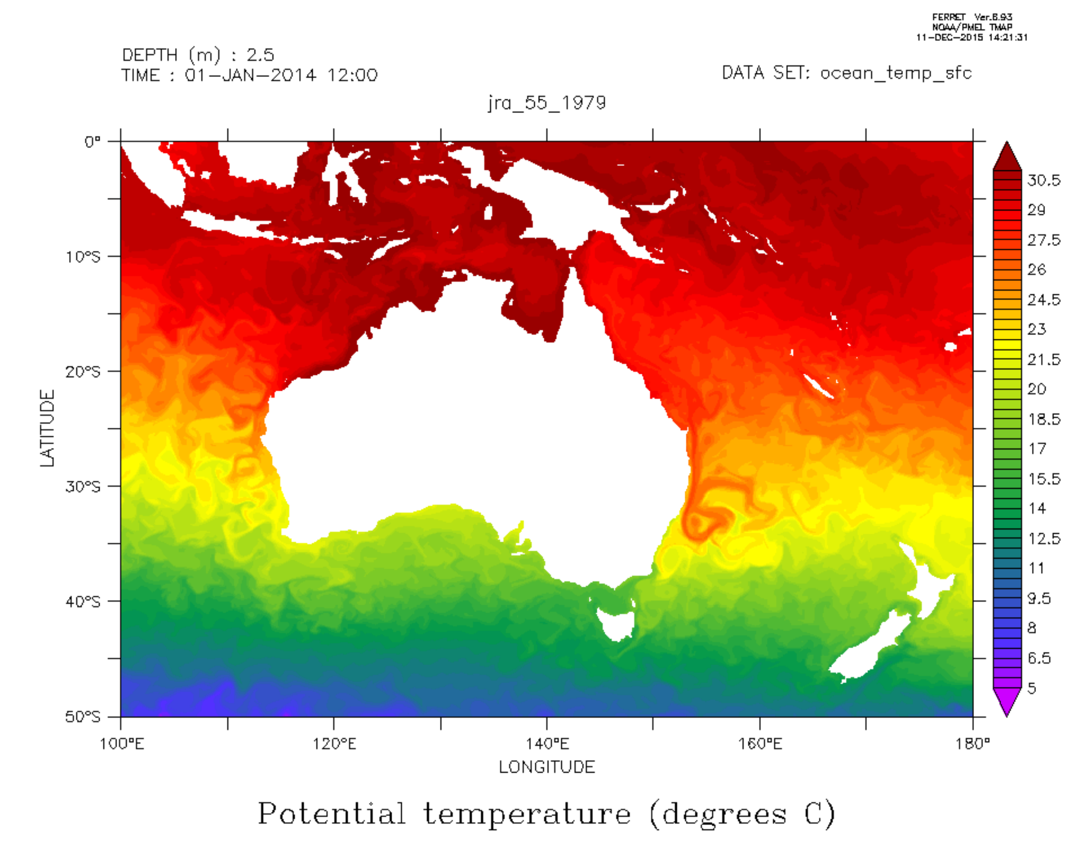

Dynamical downscaling of climate changes with OFAM3

OCEANS AND ATMOSPHERE
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CSIRO Ocean Downscaling Strategic Project: *Xuebin Zhang, Peter Oke, John Church (UNSW), Ming Feng, Richard Matear, Andreas Schiller, Chaojiao Sun, Matt Chamberlain, Didier Monselesan, Russ Fiedler and Clothilde Langlais*

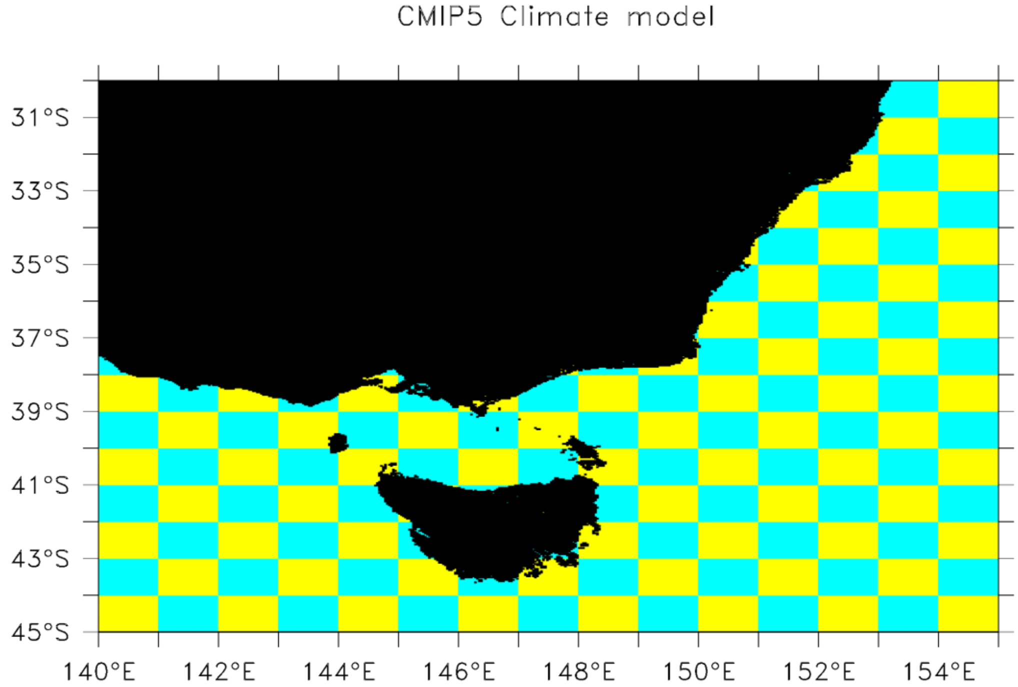
Background

- The CMIP climate models are usually designed to provide large-scale climate change and variability information, but end users often want to know localized information for better adaptation planning.
- Some leading centres (e.g., GFDL) have been developing high-resolution coupled climate models, however they are usually expensive to run and thus won't be widely available in coming years.
- In coarse-resolution models (coupled or ocean-only), some oceanic processes can't be resolved but are represented through parameterization. In particular, meso-scale eddies are often absent from climate models, but they are important for heat transport and exchange (Griffies et al. 2015), oceanic kinetic energy budget (Ferrari and Wunch 2008), and BGC processes such as supply of nutrients to the upper ocean (McGillicuddy et al. 1998).

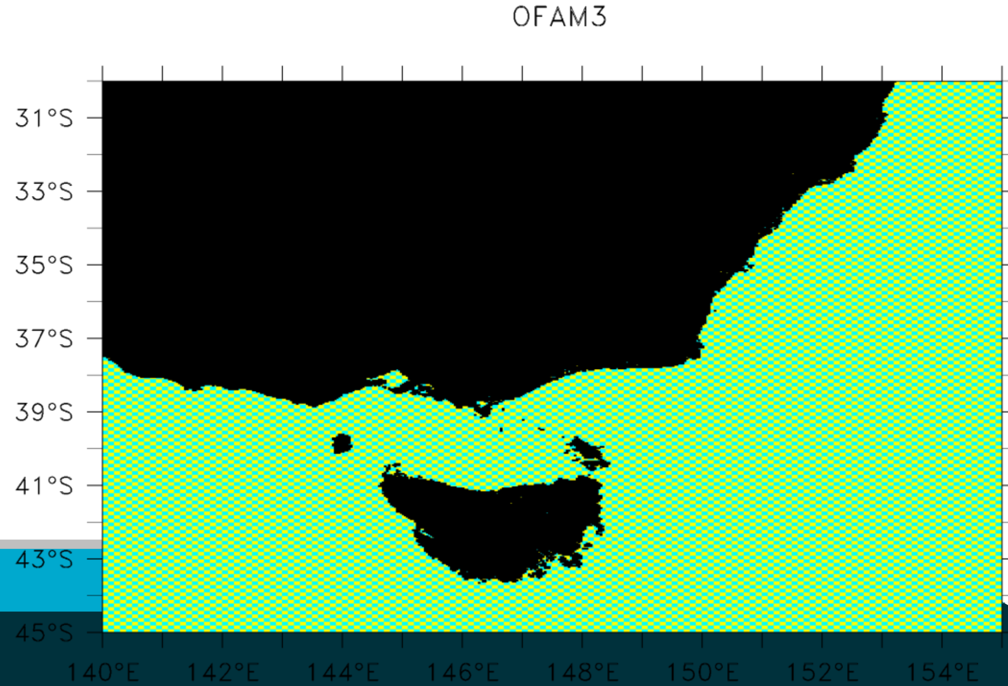
Coarse-resolution climate model grid (1°)

versus

high-resolution ocean grid (0.1°)



1°x1°
CMIP5



0.1°x0.1°
OFAM3

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CSIRO Ocean Downscaling Strategic Project

- ***Mission***: *Provide high-resolution climate change and variability information in the ocean over the past several decades and in the future, for better understanding, adaptation and mitigation purpose. (Experimental & Application-oriented!)*

- ***Methodology - Dynamical downscaling:***

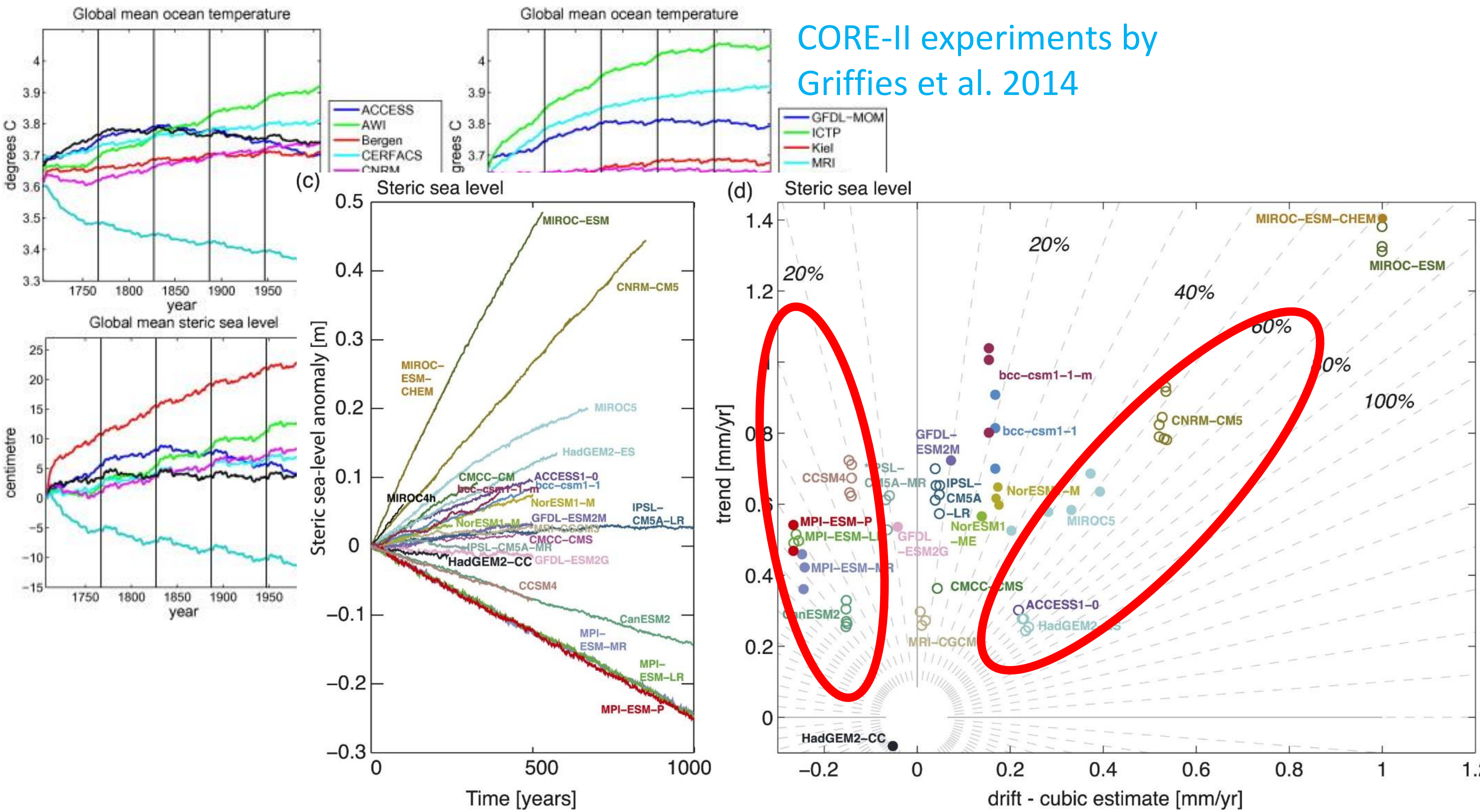
  How does the OGCM respond to climate change "perturbation" derived from CMIP climate models

  - Derive present ocean climate: integrate a near-global 1/10º OGCM (OFAM3, based on MOM4p1) with atmospheric reanalysis products $\mathbf{F_{present}}$.
  - Estimate climate change signals from CMIP5 climate models: $\mathbf{\Delta F_{CMIP5}}$
  - Derive future ocean climate: integrate the OGCM with merged future forcing $\mathbf{F_{future} = F_{present} + \Delta F_{CMIP5}}$.
  - The "downscaled" ocean changes are derived by comparing present and future ocean states.

Challenges!

- *It's very time-consuming and "expensive" to run a global eddy-resolving model. In the beginning when we planned this project, simulation of one model year took ~3 days (later one year per day). But we wished to run it >100 years.*
- *The project was originally funded for one year.*
- *Nonetheless, it takes long time (multiple decades to centuries) to spin up global models. Model drift is a long-standing problem, not only in ocean-only models, but also in coupled climate models. We need to minimize the drift so that it doesn't contaminate the climate change signals of our interest.*

Model Drift



CORE-II experiments by Griffies et al. 2014

CMIP5 models by Sen Gupta et al. 2013

Near-global 1/10° Ocean Model – OFAM3 (Oke et al. 2013, Zhang et al. 2016, 2017; Feng et al. 2016, 2017)

- Ocean Forecasting Australia Model – version 3 (OFAM3), based on GFDL MOM4p1
- Near-global domain (w/o Arctic), 75°S – 75°N, 0.1°x0.1°
- 51 vertical layers, 5 m resolution down to 40 m, then 10 m resolution down to 200 m.
- Bulk formula forcing with atmospheric reanalysis products
- Used with data assimilation for Bluelink ReANalysis (BRAN).
- Include WOMBAT BGC model

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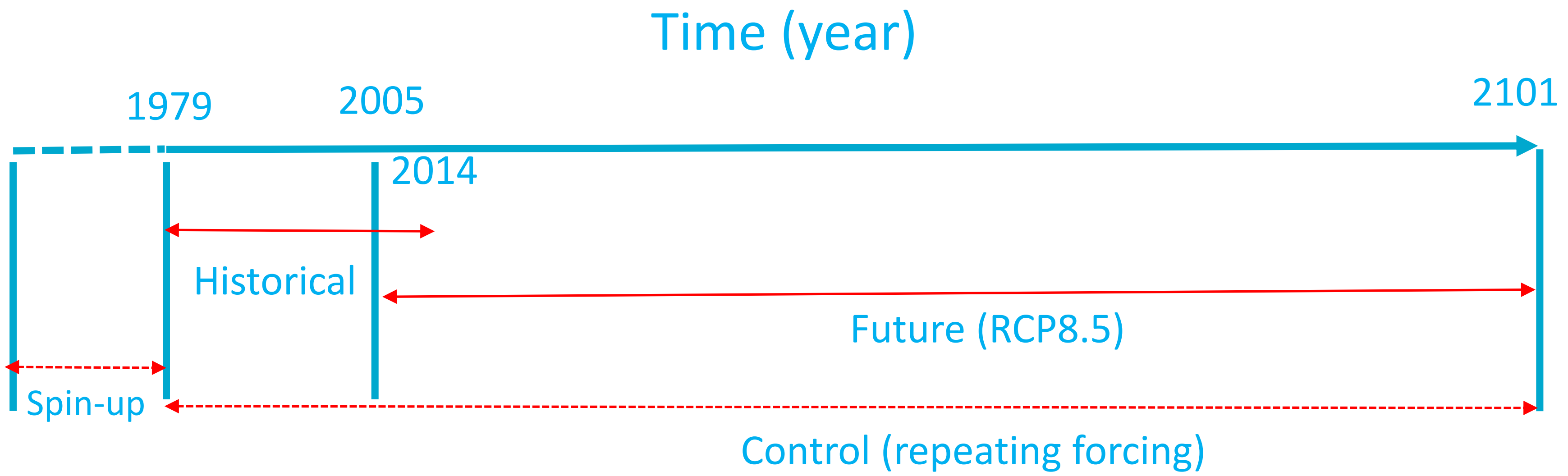
Model experiments



Model experiments

Experiments	Period	Initial condition (IC)	Forcing	T/S relaxation	Purposes
Spin-up	1979 (repeating for 20 years)	Cold start	Year 1979 forcing from JRA-55	Adaptive	Spin up the model and provide IC for other runs; derive T/S relaxation climatology
Historical	1979-2014 36 years	End of spin-up	JRA-55	Non-adaptive	Current-day ocean climate; IC for future run; validate model design with observations
Future	2006-2101 96 years	End of 2005 from historical run	Merged JRA-55 and CMIP5-RCP8.5	Non-adaptive	Future ocean climate
Control	1979-2101 123 years	End of spin-up	Year 1979 forcing from JRA-55	Non-adaptive	Quantify drifts in historical and future runs

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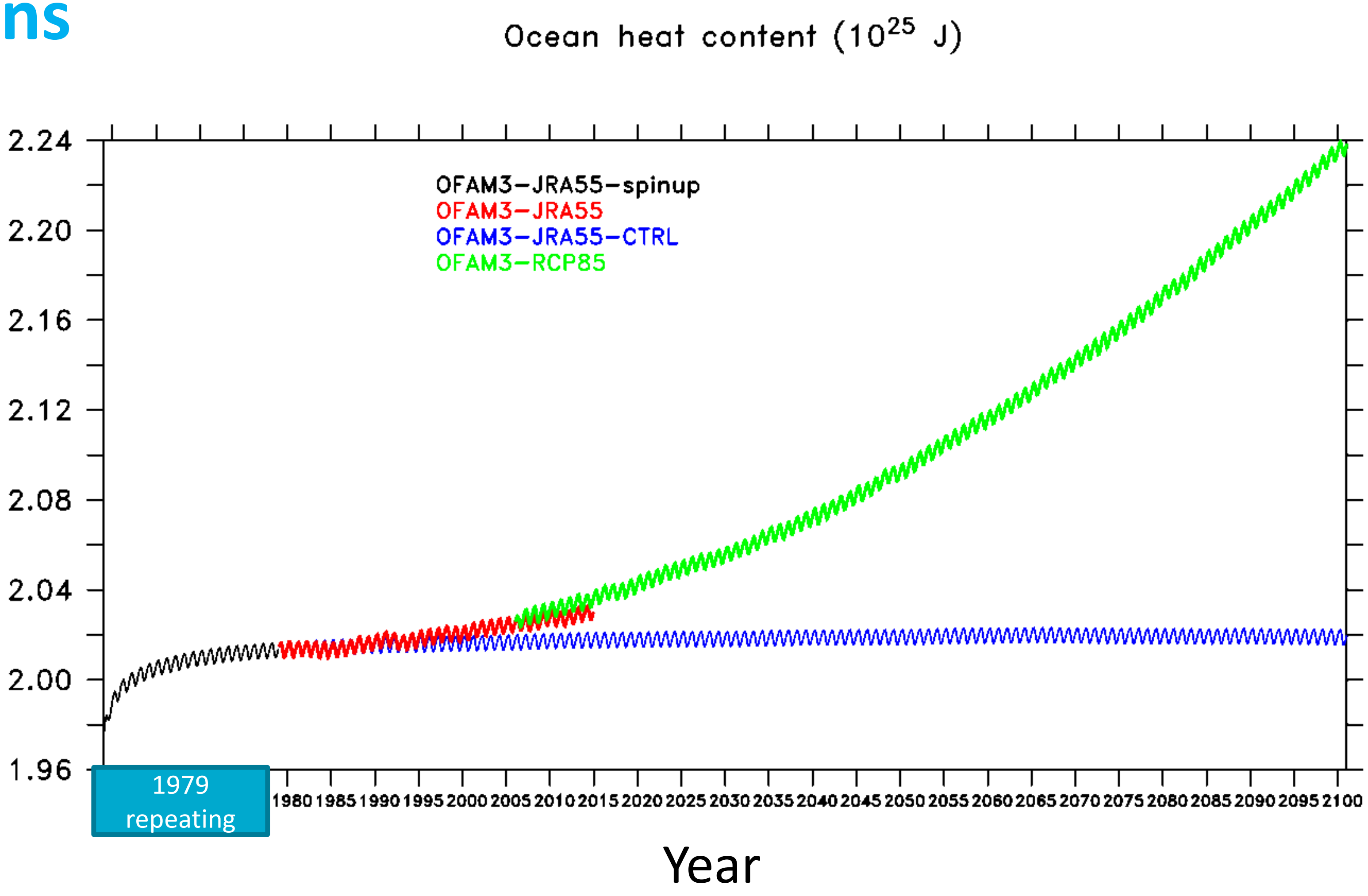
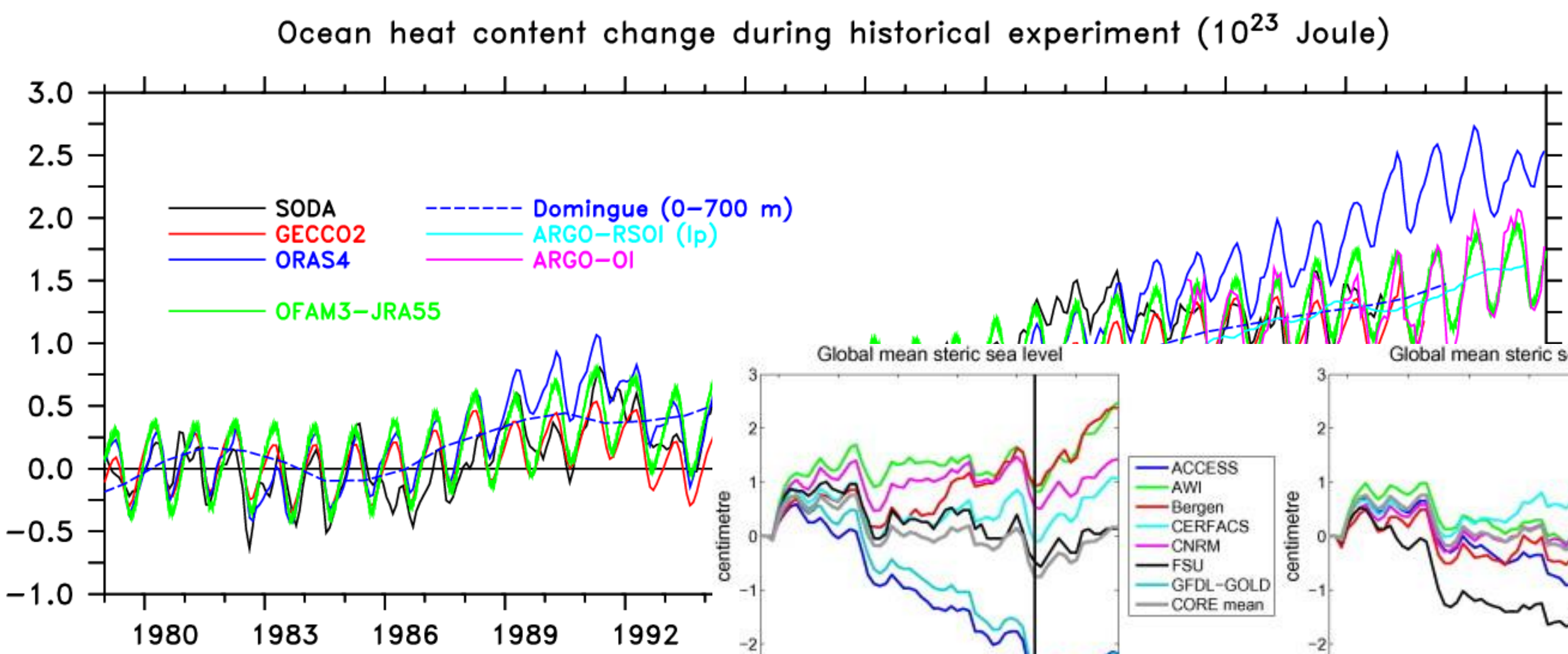
OHC from spin-up, historical, future and control runs

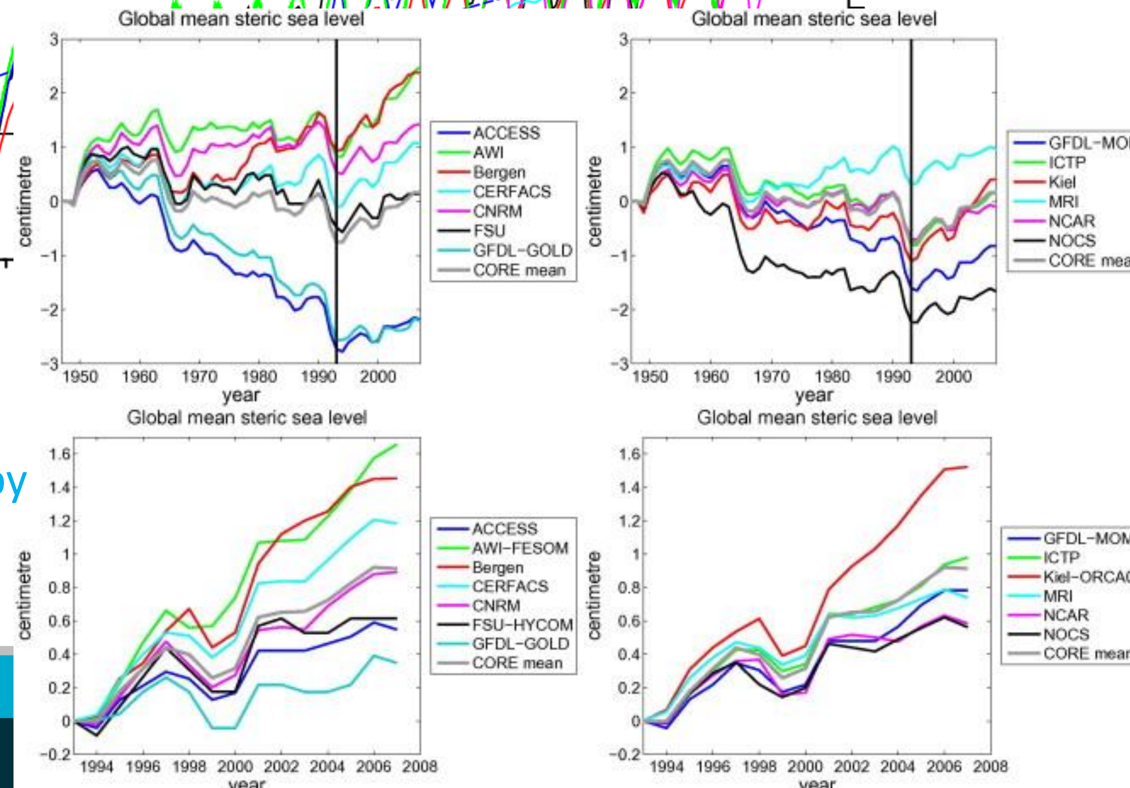


Historical run over 1979-2014 (Zhang et al. 2016)

- Driven by 3-hourly JRA-55 reanalysis through bulk formulas
- Initialized from the last year of 20-year spin-up run.
- Non-adaptive T/S relaxation, derived from the last 5 years of spin-up run, repeats itself year after year, below 2000 m and in the northern boundary.
- Constant heat flux correction derived from the spin-up run is applied too.
- Validated with many observations

Global ocean heat content from OFAM3-JRA55 historical run and three ocean reanalysis products, two Argo products, and one historical reconstruction (Domingues et al. v3.1)





CORE-II experiments by Griffies et al. 2014

Future run over 2006-2101

- Initialized from the end of 2005 year simulation from historical experiment (consistent with IPCC-AR5)
- Driven by merged forcing with high-frequency component coming from current-day JRA-55 reanalysis and long-term climate changes derived from the ensemble of 17 CMIP5 models under RCP8.5.
- Combined future forcing =

present mean state (F_{mean}) from JRA-55 +

(repeating) high-frequency variability (F_{HF}) from JRA-55 +

long-term climate change component (ΔF_{CC}) from the ensemble of CMIP5 models,

i.e., $F = F_{mean} + F_{HF} + \Delta F_{CC}$

CMIP5 ensemble

- 9 atmospheric & oceanic variables:

zonal & meridional wind, surface air temperature, specific humidity, precipitation, downward long & short wave radiation, ice concentration, sea surface salinity (relaxation)

- from the Ensemble of 17 CMIP5 models:

“ACCESS1-0", "ACCESS1-3", "BNU-ESM", "CanESM2", "CNRM-CM5", "CSIRO-Mk3-6-0", "GFDL-CM3", "GFDL-ESM2G", "GFDL-ESM2M", "GISS-E2-H", "IPSL-CM5A-MR","IPSL-CM5B-LR", "MIROC5", "MIROC-ESM-CHEM", "MIROC-ESM", "MRI-CGCM3", "NorESM1-M"

Data processing for JRA-55 reanalysis

- Derive monthly means from 3-hourly data
- Apply band-pass filtering (cut-off period ~7 years with lanczos filter) to monthly data, get high-passed component (interannual and shorter time scales) and low-pass components (mainly decadal and longer time scale).
- Remove the low-pass component (F_{LF}) from the original 6-hourly data, get the 6-hourly residual (F_{HF}) which contains variability from daily to interannual (7 years).
- High frequency component (daily to interannual) F_{HF} over 1981-2012 is repeated three times over 2006-2037, 2038-2069, 2070-2101, respectively
- Derive a long-term mean state (F_{mean}) over 1986-2005 period either from the original 6-hourly data or monthly data.

Data processing for CMIP5 climate models

- Derive the long-term (or low-frequency) signals from a climate model by **running mean over a sliding 20-year window**.
- Derive the change of above low-frequency component relative to the current-day (1986-2005) mean, which is regarded as the long-term climate change component (ΔF_{mean}).
- Derive the ensemble average [ΔF_{mean}] by averaging ΔF_{mean} from individual models.

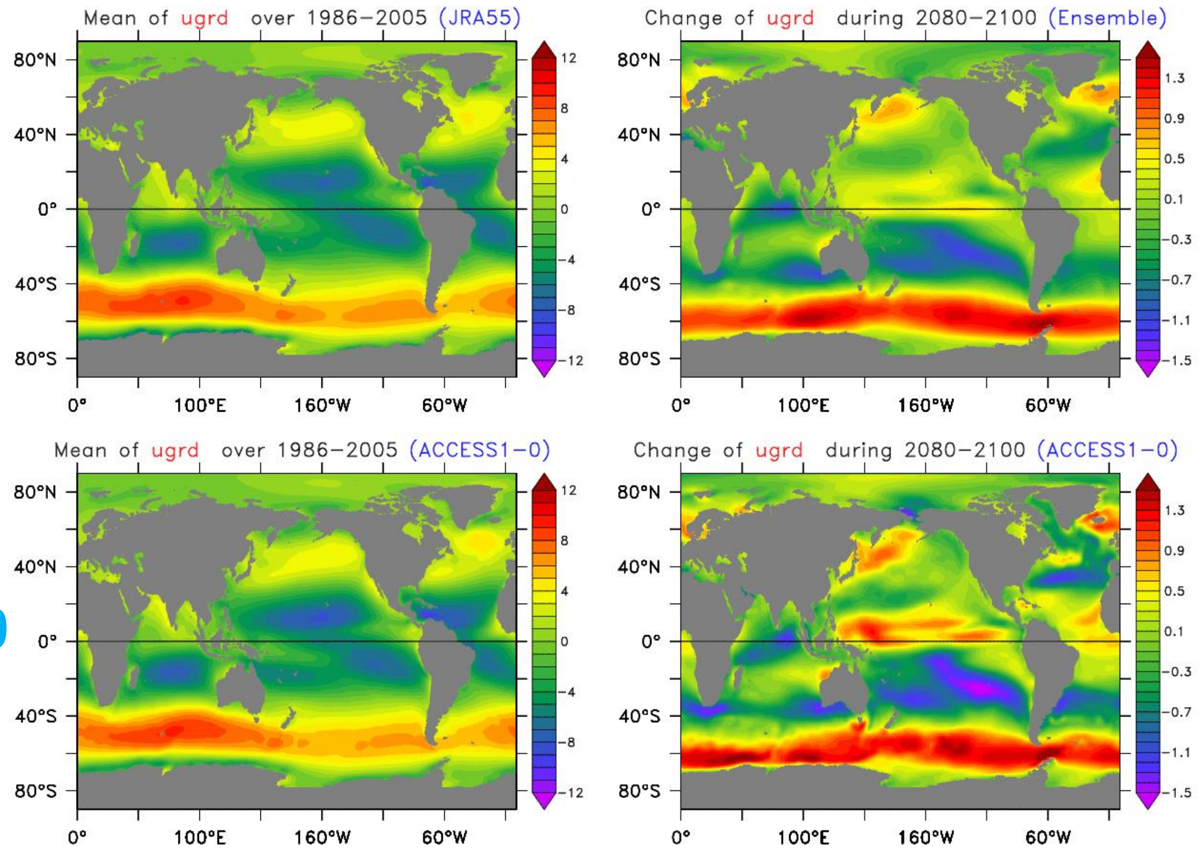
Example of forcing field – zonal wind

JRA55

CMIP5 Ensemble

ACCESS1.0

ACCESS1.0



(1986-2005)

(2081-2100) – (1986-2005)

Some thoughts about future perturbation experiments

- Derive forcing from one climate model vs multiple climate models, either individually or collectively (ensemble mean)
- Climate forcing: filtered or unfiltered
- Climate change signals applied instantly (e.g., FAFMIP) or gradually (over years/decades)?
- Bulk-formula vs flux-form forcing
- Physical only or physical + BGC
- Up to 2100 or beyond 2100 (e.g., 2200)

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Forcing decomposition

Current-day climate

$$F_C = F_{mean} + \begin{cases} F_{seasonal} \\ F_{non\text{-}seasonal} \end{cases}$$

- $F_{seasonal}$
- $F_{non\text{-}seasonal}$
  - $F^{HF}_{non\text{-}seasonal}$ (weather, intraseasonal ... interannual)
  - $F^{LF}_{non\text{-}seasonal}$ (decadal ...)

climate change signal

$$\Delta F = \Delta F_{mean} + \Delta F_{seasonal} \,?\, + \Delta F^{LF}_{non\text{-}seasonal} \,?\, + \Delta F^{HF}_{non\text{-}seasonal} \,?$$

Future climate

$$F_F \approx F_C + \Delta F$$

Thank you

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Selected publications:

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- Hobday, A. J., C. M. Spillman, P. Eveson, J. Hartog, X. Zhang, S. Brodie, 2018: A framework for combining seasonal forecasts and climate projections to aid risk management for fisheries and Aquaculture, Front. Mar. Sci., 5, 137, doi: 10.3389/fmars.2018.00137.
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